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About nuclear spin kinetics in solid ^{3}He at magnetic field

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Abstract

It is shown that the nuclear spin system of solid ^{3}He in paramagnetic phase cannot be divided into two almost independent subsystems (the Zeeman reservoir and the exchange reservoir) in case when the Zeeman energy exceeds the heat energy. The introduced representation about spin excitons in nuclear system of solid ^{3}He at a rather high magnetic fields allows to eliminate the reasons for the appearance of strong thermodynamic coupling between subsystems. The preliminary calculations give the evidence that an effective cooling of solid ^{3}He nuclear spin system can be achieved at NMR saturation and show that important information about the validity of taking into account the spin–spin interactions of different nature can be obtained from nuclear spin lattice relaxation measurements at these conditions.

Keywords: Solid ^{3}He; NMR; spin kinetics; multiple spin exchange

The magnetic properties of solid ^{3}He have been under intensive studying during many years [1–4] and a big progress has been achieved in the understanding of magnetic ordered phases. At the same time there were no such investigations for paramagnetic phase. Probably it is connected with the fact that due to the most strong spin–spin interactions–exchange and multiple exchange interactions between nuclear spins [3]—the NMR line-shape is extremely narrowed and it should not be any resonance frequency shift in the magnetically disordered state. In this work we show that investigations of nuclear spin kinetics of solid ^{3}He in paramagnetic phase at a rather high magnetic fields can provide an interesting physical information.

1. Spin excitations

The Hamiltonian for nuclear spin system of solid ^{3}He in external magnetic field H_0 directed along z-axes can be written in quite general form as

$$H = H_Z + H_{ss} \quad (1)$$

where $H_Z = \gamma_n \hbar \sum_j I_j^z H_0$ represents the Hamiltonian of the Zeeman interactions of spins whose gyromagnetic ratio is denoted as γ_n. The Hamiltonian of spin–spin interactions H_{ss} may include usual exchange interactions between spins, multiple spin exchange interactions and dipole–dipole interaction although the strength of the latter is very small. Namely the exchange energy is of order 1 mK whereas the dipole energy ia about 10^{-4} mK. The explicit form of H_{ss} is not important now and can be found in literature.

We are interested here in studying only the paramagnetic phase of solid ^{3}He. It denotes that temperatures above 1 mK should be considered. At magnetic fields well above 2 T the Zeeman energy exceeds all other magnetic energies as well as the heat energy $(\gamma_n \hbar H_0/k_B T) \gg 1$ so the ground state of the spin system corresponds to the alignment of all spins along external magnetic field direction. Any excited state can be considered in terms of some elementary spin excitations. They are not magnons in full sense because their energy is determined mostly by the Zeeman energy. Spin–spin interactions lead to the appearance of an energy zone for such excitations. When the condition $\gamma_n \hbar H_0/k_B T \gg 1$ is satisfied the number of these spin excitations is small and they can be considered as non-interacting bosons. The average energy of spin excitons

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